Sensor technologies for the detection of antipersonnel mines
A survey of current research and system developments

Bertrand Gros and Claudio Bruschini

EPFL - LAMI
DeTeC*
IN F - Ecublens
1015 Lausanne
Switzerland
E-mail : Bertrand.Gros@di.epfl.ch and Claudio.Bruschini@di.epfl.ch

Abstract

Detecting minimum metal antipersonnel mines and distinguishing them from the metallic debris of a minefield is difficult with the currently available metal detectors. Several promising new technologies are in development, but no single sensor will be reliable enough to find every mine in every situation, hence the need for sensor fusion. It is of primary importance that scientists in each discipline share their knowledge and the result of their experiments in order to design solutions for humanitarian demining.

1. Introduction

More than 100 million mines have been laid in the world, killing or maiming innocent civilians every day. Hence the need for the scientific community to use its knowledge to help stopping this plague for the humanity.

In the following paragraphs we review a number of technologies and projects on the subject of mine detection. We certainly cannot claim to be exhaustive : most of the projects conducted during the last years were targeted at military applications and detailed information is rarely published.

Fortunately, a number of conferences specialized on this topic have taken place recently and help to have a clearer view of the research currently in progress [1].

It must be noticed that solutions developed for the military are normally not suitable for humanitarian demining. In the first case the goal is to make quickly a breach in a minefield to allow the troops to progress without delays. Mine finding or destruction rates of typically 80% are accepted. For humanitarian mine clearing it is obvious that the system must have a detection rate approaching the perfection (UN specifications require better than 99.8%). The armies being more and more implicated in peace keeping operations (Bosnia, Somalia), their requirements will surely come closer to the ones above.

2. Sensors currently used for manual demining

Demining teams use metal detectors that work by measuring the disturbance of an emitted electromagnetic field caused by the presence of metallic objects in the soil.

In some cases magnetometers are employed, mostly for ferromagnetic objects. These sensors do not radiate any energy, but only measure the disturbance of the earth's natural electromagnetic field.

Both types of detectors cannot differentiate a mine from metallic debris. In most battlefields

* The DeTeC (Demining Technology Center) team has been created in 1995 by Prof. J.-D. Nicoud at the "Ecole Polytechnique Fédérale de Lausanne" (EPFL) with the goal of developing a robotized solution for humanitarian demining. The corresponding World Wide Web homepage is http://diwww.epfl.ch/w3lami/detec

the soil is contaminated by large quantities of shrapnel, metal scraps and cartridge cases, leading to 100-1000 false alarms for each real mine. Each alarm means a waste of time and induces a loss of concentration.

Newer mines have almost no metal parts, the needle of the detonator excepted. Although the detectors can be tuned to be sensitive enough to detect these small items (current detectors can track a tenth of a gram of metal at a depth of 10 cm), this is not practically feasible, as it will also lead to the detection of smaller debris and augment the false alarms rate.

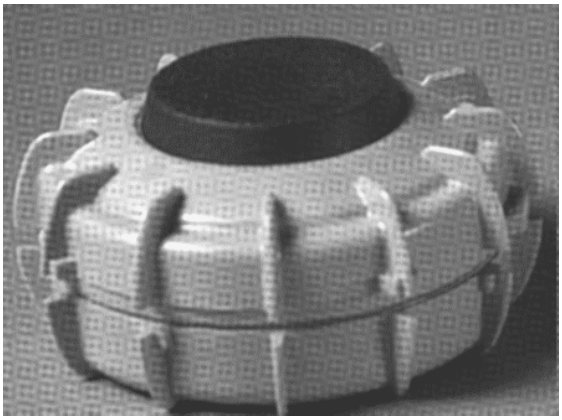

Fig. 1 The VS50, an antipersonnel mine with low metal content

To find these minimum metal mines, the only current alternative is to use prodding. Using rigid sticks of metal, about 25 cm long, the deminer scans the soil at a shallow angle of typically 30°. Each time he feels something, he must check the contour of the object to determine if it is a mine. This is dangerous because the mine could have moved and the sensitive surface turned straight to the operator.

3. Current research and system developments

From the above considerations it is obvious that new technologies must be developed to increase the detection rate and to automate these tasks whenever possible to preserve the life of the mine clearing personnel.

We list here a sample of the most important ones. A more systematic survey can be found in [13].

3.1 Ground Penetrating Radar (GPR)

The GPR technology has been used for about 15 years in civil engineering, geology and archeology for the detection of buried objects and soil study.

GPR works by emitting into the ground, through a wideband antenna, an electromagnetic wave covering a large frequency band. This can be done by using a short pulse or a pure sine wave whose frequency is varied continuously or by steps to cover the desired range. Reflections from the soil caused by dielectric variations such as the presence of an object are measured. By moving the antenna it is possible to reconstruct an image representing a vertical slice of the soil [2].

A wide frequency band is needed to achieve a good resolution, but since higher frequencies do not propagate well, the chosen range is always a tradeoff between resolution and penetration depth. For antipersonnel mines, a center frequency of 1 to 2 GHz seems to be a good choice for most types of soil.

The GPR is able to detect non-metallic materials as long as their dielectric characteristics are sufficiently different from the surrounding media.

It must be noticed that systems used in civil applications do not have any automatic recognition algorithms implemented; this is therefore the domain where most of the work has to be done, to allow the use of this technology for mine detection.

The FOA team in Sweden has started a project on this subject, using a 0.3-3 GHz GPR system. Currently published results show the feasibility of the detection of mine-like objects; the next step will be the addition of adaptive and target classification algorithms [3].

The Lawrence Livermore National Laboratory (LLNL) has developed and patented a new technology, the Micropower Impulse Radar (MIR) [4]. This radar is characterized by its compact size, light weight and low cost. The small footprint of the antennas (less than 50 cm^2) allows to build quite easily an array for a faster and simplified scan of the minefield. First published results on anti-tank mines show interesting pictures produced by a 3D imaging software generating horizontal slices of the soil, although the processing time and needed computer power are not specified.

The European Microwave Signature Laboratory (EMSL) has conducted experiments on antipersonnel mines using frequencies ranging from 2 to 6 GHz [7]. They have demonstrated good imaging capabilities for surface-laid mines and mines buried at a shallow depth in sand. But it must be noticed that at such frequencies the penetration depth could be insufficient in other materials and that the move to the field could be difficult, these experiments having been carried out in ideal laboratory conditions (anechoic chamber).

Another approach with GPR is to look for complex resonances. A study conducted in the 1970's at the Ohio State University has already demonstrated the possibility of recognizing targets of about 30cm buried in clay by detecting resonances in the spectrum of the reflected signal. These resonances being specific to each target type. New studies are in progress at that university for the detection of unexploded ordnance using that method [8]. An other US team, at EG&G, conducts research in the same direction, studying in addition resonances in metal detectors response [9].

Description of some non-commercial GPR systems, as used in the US Army CIMMD project, are given in [5][6].

3.2 Induction coil sensor imaging

Instead of converting the information given by the induction coil sensor, used in conventional metal detectors, to an audio signal, it is possible to use it for imaging purposes. By moving the sensor and displaying data using different colors for different response amplitudes a map of the metal content in the soil can be constructed.

The ODIS project at DASA-Dornier [10] has demonstrated encouraging results in the detection of unexploded ordnance. In its current version it is able to detect metal parts of less than $1cm^3$. Penetration depth is about 50cm.

Using appropriate software, the system is able to compute the magnetic center of an object (±2cm), its depth (±10%) and its metallic volume. The phase information is used to determine the type of metal. Currently the system is only able to differentiate between ferromagnetic and non-ferromagnetic material, but an amelioration of the phase measurement could allow a better metal determination.

The current prototype is quite heavy, but a study has demonstrated the feasibility of a man portable system.

3.3 Infrared imaging

Mines retain or release heat at a different rate than their surrounding. During natural temperature variations of the environment it is possible to measure the thermal contrast using infrared cameras. Developments in this technology are mainly targeted at airborne recognition of minefields.

The development of a short range system for the US army by Martin Marietta Technologies Inc. is an example of the few projects aimed at searching individual mines. It is based on a commercial 8-12μm IR sensor and uses neural networks to recognize patterns after segmentation of the image. They report 90% of target detection at the current stage of the project [14].

3.4 Explosive vapor sensors

Dogs are used for the research of mines because their great smell sensibility (10^{-12} to 10^{-13} g of explosive) allows them to detect mines with a good reliability. But their training is expensive and they get rapidly tired.

Artificial odor or vapor sensors would constitute a valid alternative : in fact they exist and are already used in the chemical industry or in airports (chemiluminescence [18], mass spectrometry, ion mobility spectroscopy, biosensors, electron capture [19][20]). Unfortunately these sensors either have a too low sensibility, are too slow or too large to be used in field applications.

The Bofors company in Sweden has launched in 1995 a project targeted specifically at the detection of antipersonnel mines using odor sensors based on antibodies, coupled with other sensor technologies such as GPR [11]. It basically works by measuring the variation in the oscillating frequency of a piezoelectric crystal, whose surface is covered by an antibody reacting with the molecules of TNT.

Concerning the drawbacks of this mine detection technique, it must be noticed that experience with dogs seems to show that mines do not release significant TNT vapor after 18 months of burial. For this reason it could be necessary to induce the evaporation of molecules of explosive using microwaves.

In addition, the explosive's odor can penetrate the ground and the vegetation in an area up to 10 meters from the real location of the mine after some months, leading to difficulties in locating its real position [12].

3.5 Bulk explosive detection

Amongst the techniques which could be used to detect the explosive charge itself, nuclear detection methods are the most promising at the current stage of development (see [21] for an overview of applications in the aviation security sector). Thermal Neutron Activation (TNA) in particular relies on the activation, via neutrons emitted by a radioisotopic source or an accelerator, of the nitrogen nuclei abundantly contained in most explosives. Specific gamma rays are emitted and detected.

In particular, the SAIC company has developed a system using a Californium-252 source for the Canadian Forces. It has been selected as a confirmatory detector for the Improved Landmine Detection System (ILDS) that includes a GPR, an array of metal detectors (the Schiebel VAMIDS system) and a forward looking IR camera [22].

Drawbacks of this method, apart from system complexity, are the limited depth of penetration (10-20 cm) and the potential danger for the operator due to the neutron source.

X-ray backscatter techniques are also being investigated and some system developments are described in [23][24].

3.6 Millimeter wave emission detection

In the millimeter wave band, soil has a high emissivity and low reflectivity. On the other side, metal has a low emissivity and strong reflectivity. Soil radiation depends therefore almost entirely on its temperature and metal reflection mostly on the low level radiation from the sky. It is possible to measure this contrast using a millimeter wave radiometer device (in the frequency range from 30 to 300 GHz). Tests in ideal laboratory conditions have demonstrated the capability to detect metallic objects buried under 3 inches of dry sand [15].

4. Data fusion in multisensor systems

No single sensor technology has the capability of reaching a good detection rate while having a low false alarm rate in all types of soil, with all types of mines and with all types of false targets. Hence the need to use complementary sensor technologies and to do an appropriate sensor data fusion.

For example, the addition of a metal detector to a GPR system could help in case of doubt between a mine and a stone of the same size, which could have similar echoes. At the opposite, the GPR could differentiate a mine from a debris, which could have the same amount of metal and therefore an identical answer with a metal detector.

We, at DeTeC, have chosen in a first step to use both GPR and induction coil imaging. Both technologies offer readily available hardware solutions, but a lot of work needs to be done on the software side, particularly for target identification. First experiments will be started in spring 1996 in a sandbox equipped with a computerized system for the automated positioning of the sensors. Information on the progress of our experiments will be published regularly on our WWW page.

Multi-sensor fusion will be applied for example in the US Army Improved Ground Mobile Mine Detection Testbed (IGMMDT), one of the many projects directed by the Night Vision and Electronics Sensors Directorate. Two competitive strategies from EG&G and Geo-Centers will be evaluated in the first half of 1996 [16]. They both rely on the use of a GPR coupled with IR cameras and in the EG&G case also with metal detectors [9]. These systems, together with the Canadian ILDS mentioned above, are mainly targeted at the detection of anti-tank mines. Nevertheless we expect that some of their hardware components, and possibly most of the software, will be useful also for the search of antipersonnel mines.

5. Conclusion

Whatever solution is chosen, its cost must not be neglected in view of its application to humanitarian demining. A NATO report published in March 1996 [17] has made an classification of potential technologies, given in the next table.

Sensor technology	Maturity	Cost and complexity
Passive infrared	Near	Medium
Active infrared	Near	Medium
Polarized infrared	Near	Medium
Passive electro-optical	Near	Medium
Multi-hyperspectral	Far	High
Passive mm-wave	Far	High
mm-Wave radar	Near	High
Ground penetrating radar	Near	Medium
Ultra-wideband radar	Far	High
Active acoustic	Mid	Medium
Active seismic	Mid	Medium
Magnetic field sensing	Near	Medium
Metal detection	Available	Low
Neutron activation analysis	Near	High
Charged particle detection	Far	High
Nuclear quadrupole reson.	Far	High
Chemical sensing	Mid	High
Biosensors	Far	High
Dogs	Available	Medium
Prodding	Available	Low

It is clear that no single technology has the capability to detect and recognize a mine in all situations. Costs and efficiency must be compared, hence the need for a better exchange of information between the specialists in each category.

In that optic, the DeTeC team has decided to make available through the Web the data files (along with all the necessary documentation) resulting from the acquisitions with its GPR and induction sensor. We hope that teams with greater expertise in one domain (as for example image processing), but without the necessary funding to build all the hardware setup needed to conduct experiments, will help to make the research progress.

References

[1] Nicoud J.D., "Mine clearance - Not only a problem for the military any more", Measurement and Control in Robotics, ISMCR'96, Bruxelles, May 96.

[2] Daniels D.J., Gunton D.J., Scott H.F., "Introduction to subsurface radar", IEE Proceedings, Vol. 135, Pt. F, No. 4, August 1988, pp. 278-320

[3] Brusmark B., Abrahamson S., Axelsson D., Gustafsson A., Strifors H., "Evaluation of experimental data from a GPR system for detection and classification of buried mines", Proceedings GPR'94, Kitchener (Canada), June 1994, pp. 639-643

[4] Azevedo S.G., Gavel D.T., Mast J.E., Warhus J.P., "Statement of Capabilities : Micropower Impulse Radar (MIR) Technology Applied to Mine Detection and Imaging", Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551, March 95

[5] Sherbondy K.D., Lang D.A., "Developmental GPR mine detection technology known as the balanced bridge", SPIE proceedings, vol. 2496, Orlando, April 1995, pp. 31-41

[6] Barrett C., Nicoloff M., Patz M., Steinway W., Stern P., Thomas J., "Measurement results from the Technology Assessment for Close-in Man Portable Mine Detection (CIMMD) program", SPIE proceedings, vol. 2496, Orlando, April 1995, pp. 76-83

[7] “Test Measurements for the Detection of Anti-Personnel Land Mines”, EMSL, Ispra, August 1995

[8] Peters L.Jr., Daniels J.J., Young J.D., “Ground Penetrating Radar as Subsurface Environmental Sensing Tools", Proceedings of the IEEE, Vol. 82, No. 12, December 1994, pp. 1802-1822

[9] Sower G.D., Cave S.P., "Detection and identification of mines from natural magnetic and electromagnetic resonances", SPIE proceedings, vol. 2496, Orlando, April 1995, pp. 1015-1023

[10] Borgwardt C., “ODIS - Ordnance Detection and Identification System”, Workshop on Anti-Personnel Mine Detection and Removal WAPM’95, EPFL-LAMI, Lausanne, July 95, pp. 37-43.

[11] “Bofors’ demining concept”, brochure from Bofors, Celsius Group, SW-69180 Karlskoga, not dated.

[12] “Trends in Land Mine Warfare", Special report, Jane's Information Group, August 1995, 161 pages.

[13] Craib J.A., “Survey of mine clearance technology", Conducted for the United Nations University and the United Nations Department of Humanitarian Affairs

[14] Ngan P., Garcia S.A., Cloud E., Duvoisin H., Long D., Hackett J., “Development of automatic target recognition for infrared sensor-based close range land mine detector", SPIE proceedings, vol. 2496, Orlando, April 1995, pp. 881-889

[15] Yujiri L., Hauss B., Shoucri M., “Passive milimeter wave sensors for detection of buried mines", SPIE proceedings, vol. 2496, Orlando, April 1995, pp. 2-6

[16] Handshaw T., "Multi-sensor fusion for the detection of mines and mine like targets", SPIE proceedings, vol. 2496, Orlando, April 1995, pp. 152-158

[17] "Peacetime mine clearance (Humanitarian demaining)", NATO Defence Research Group, unclassified document AC/243-D/1213

[18] Patel D.L., "Best type of sensors for the detection of buried mines", Proc. Of the Autonous Vehicles in Mine Countermeasures Symposium, Monterey, April 1995, pp. 6.48-6.59

[19] Mächler Ph., "Detection technologies for anti-personnel mines", Proc. Of the Autonous Vehicles in Mine Countermeasures Symposium, Monterey, April 1995, pp. 6.150-6.154

[20] Jankowski P.Z., Mercado A.G., Hallowell S.F., "FAA Explosive vapor/particle detection technology", SPIE proceedings, Vol. 1824, 1992, pp. 13-24

[21] Novakoff A.K., "FAA Bulk Technology Overview for Explosive Detection", SPIE proceedings, Vol. 1824, 1992, pp. 2-12

[22] Hewish M., Ness L., "Mine-Detection Technologies", International Defense Review, Vol. 28, October 1995, pp. 40-45

[23] Wehlburg J., *et al.*, "Image restoration techniques using Compton backscatter imaging for the detection of buried landmines", SPIE proceedings, Vol. 2496, 1995, pp. 336-347

[24] Burchanowski C., Moler R., Shope S., "Scanned-beam x-ray source technology for Photon Backscatter Imaging Technique of mine detection : advanced technology research", SPIE proceedings, Vol. 2496, 1995, pp. 368-373